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# Nuclear Star Clusters in Edge-on Galaxies

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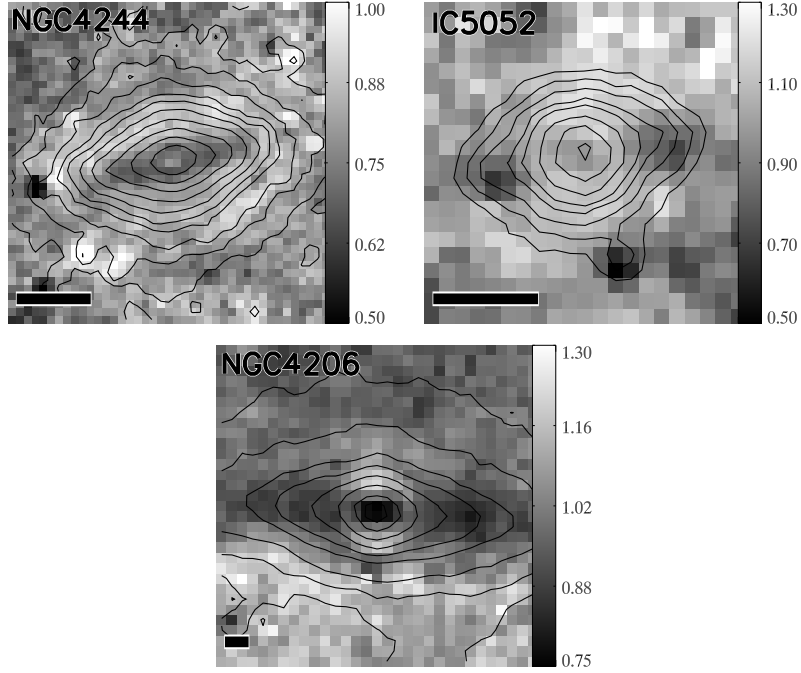
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From observations of edge-on, late-type galaxies, we present morphological evidence that some nuclear star clusters have experienced *in situ* star formation. We find three nuclear clusters that, viewed from the edge-on perspective, have both a compact disk-like component and a spheroidal component. In each cluster, the disk components are closely aligned with the major axis of the host galaxy and have bluer colors than the spheroidal components. We spectroscopically verify that one of the observed multiple component clusters has multiple generations of stars. These observations lead us to suggest a formation mechanism for nuclear star clusters, in which stars episodically form in compact nuclear disks, and then lose angular momentum, eventually forming an older spheroid. The full results of this study can be found in a forthcoming paper.

## 1 Background

Nuclear star clusters are a common feature of dwarf elliptical and spiral galaxies. Surveys of both face-on bulgeless spirals (type Scd and later) and dwarf ellipticals find that roughly 75% have a single bright star cluster as their nuclei [2, 5]. The sizes of these nuclear clusters are similar to Galactic globular clusters ( $r_{eff} \sim 3$  pc), but they are significantly brighter, with absolute *I*-band magnitudes of -8 to -16 [2, 3]. This luminosity is due both to their high masses (typically a few  $\times 10^6 M_\odot$ ) and to the presence of younger stellar populations [14, 15].

Nuclear clusters are interesting objects in a galaxy evolution context. A number of groups have recently shown that the masses of nuclear clusters correlate with their host galaxy masses along the same relation found for supermassive black holes, and thus appear to be directly connected to the process of galaxy formation [6, 10, 16]. Furthermore, observations of nuclear clusters may provide clues to the formation of unseen supermassive black



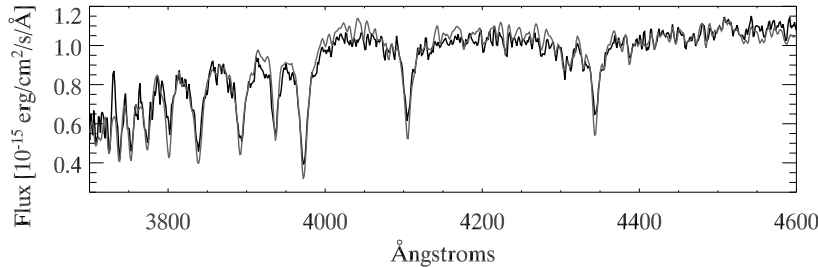
**Fig. 1.** Color maps of the three multi-component nuclear clusters overlaid with contours showing the F606W brightness. The colorbars indicate the F606W-F814W in each cluster; dark colors indicate blue regions. Each image has been rotated so that the x-axis is parallel to the major axis of the galaxy disk. The black bar in the bottom left corner indicates a length of 10 pc.

holes. Lastly, nuclear clusters are possible progenitors to massive globular clusters such as  $\omega$  Cen and ultracompact dwarfs [8, 1].

Two scenarios have been suggested to explain the formation of nuclear star clusters: (1) nuclear clusters form from multiple globular clusters accreted via dynamical friction [13], and (2) nuclear clusters form *in situ* from gas channeled into the center of galaxies [9]. In this proceeding we present evidence for the latter scenario.

## 2 Results

Our sample of galaxies consists of 14 nearby (2-20 Mpc), late-type (Sbc+), edge-on spiral galaxies observed with HST/ACS as part of a Cycle 12 snapshot program (sample details can be found in [12]). In these 14 galaxies, we identified 9 nuclear cluster candidates.



**Fig. 2.** Spectrum of the NGC 4244 nuclear cluster obtained with the Apache Point Observatory 3.5m telescope using the DIS spectrograph (black line). The gray line shows the best-fitting two-age spectrum, with stellar populations of 0.1 and 1 Gyr and a total mass of  $3.5 \times 10^6 M_{\odot}$ .

### *Nuclear Cluster Morphologies and Luminosities*

All nine of the detected cluster candidates were at least partially resolved in the HST/ACS images. Fits of convolved King profiles gave effective (half-light) radii ranging from 1 to 20 pc, with most of the clusters having effective radii between 1 and 4 pc. This size range is similar to what has been found previously for nuclear star clusters in face-on, late-type galaxies [3]. Furthermore, the absolute *I*-band magnitudes are also similar to previously observed nuclear clusters, ranging from -8 to -15 [2].

Three of the cluster candidates (in IC 5052, NGC 4206, and NGC 4244) have unusual morphologies. As shown by the contours in Figure 1, these three candidates are elongated and appear to have both a disk-like and spheroidal component, much like miniature S0 galaxies. Fitting these clusters with both an exponential disk component and an elliptical King profile component gave much smaller residuals than single component fits.

The elongations and disk components of the three multi-component clusters are aligned to within  $10^{\circ}$  of the major axis of the edge-on galaxy disks (see Fig. 1). Previous studies of nuclear clusters have focused on face-on galaxies, making detection of similar multi-component clusters difficult.

### *Nuclear Cluster Stellar Populations*

The color maps in Figure 1 show that the multiple morphological components have clearly different F606W-F814W colors. In each cluster, the disk components are bluer than the spheroid, with a color difference  $>0.3$  magnitudes. This color difference is most simply interpreted as a difference in age, with the disk being made of younger stars than the spheroid. Although the reddening is unknown, based on Padova single-stellar population models in the ACS filters [7], the observed color difference implies that the stellar ages of the disk are younger than  $\sim 1$  Gyr.

For the nuclear cluster in NGC 4244, the nearest in our sample ( $D = 4.4$  Mpc), we obtained a long-slit spectrum of the cluster using the DIS spectrograph on the Apache Point Observatory 3.5m telescope (Fig. 2). This spectrum verifies that multiple stellar populations are present in the cluster, with the youngest component having an age of  $\sim 0.1$  Gyr. We fit the spectrum using combinations of Bruzual & Charlot models [4] assuming  $Z=0.008$ .

As would be expected from the color maps, the spectrum is much better fit by multiple stellar populations than any single stellar population. In Figure 2 we show the best fitting two-age fit with ages of 0.1 and 1 Gyr, and a mass of  $3.3 \times 10^6 M_{\odot}$ , 5% of which is in the younger 0.1 Gyr component. The luminosity of this young component matches the disk luminosity of the best morphological fit. However, many different combinations of masses and ages fit the data well, including a three-age model with a significant old (10 Gyr) component, and a constant star formation rate model.

### 3 Summary and Discussion

Three of the nine nuclear cluster candidates in our sample have young disk components ( $<1$  Gyr) in addition to an older spheroidal component. These disks cannot be formed by accretion of globular clusters and must instead be formed *in situ* from gas accreted into the nuclear regions. The multiple stellar populations observed in many nuclear clusters [15], and the direct detection of a molecular gas disk coincident with the nuclear cluster in IC 342 [11] provide additional evidence that nuclear cluster formation is an ongoing process. We propose a model for nuclear cluster formation in which the stars in the cluster form episodically in nuclear disks. Such episodic star formation would naturally result from stochastic accretion events and/or feedback from star formation. Then, over time, the stars in the disk lose angular momentum and end up in a more spheroidal component. We are currently investigating the mechanism by which the stellar disks could lose angular momentum.

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